Aperiodic metallic gratings transparent for broadband electromagnetic waves

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Abstract-In this work, we demonstrate both theoretically and experimentally that aperiodic metallic gratings can become transparent for broadband electromagnetic waves. It is shown that broadband high transmission appears in aperiodic metallic gratings (including quasi-periodic and disordered ones), which originates from the non-resonant excitations in the grating system. An optimal condition is also achieved for broadband high transparency in the grating system. The findings can be applied for transparent conducting panels, perfect white-beam polarizers, antireflective conducting solar cells, and beyond.

Broadband extraordinary optical transmission (EOT) is usually difficult to be achieved in the metallic/dielectric nanostructures. Fortunately by introducing self-similarity in the structures, people have successfully realized broadband EOT in quasiperiodic (such as Penrose-tiling) subwavelength metal/dielectric systems and also in plasmonic fractals. Physically, broadband EOT in these systems originates from resonant excitations of surface plasmons (SPs) at multiple but discrete frequencies, which restrict the transparency bandwidth and transmission efficiency in some extents. Very recently, we have utilized periodic designing to successfully make structured metals transparent for broadband infrared and terahertz waves by relying on non-resonant excitation of spoof surface plasmons (SSPs) or SPs. Similar phenomenon are further found in optical frequencies, which is explained by the anomalous impedance-matching mechanism. However, the broadband transparency in periodic systems occurs for wavelengths larger than the first-order Wood’s anomaly. Around the Wood’s anomalies, the transmission of electromagnetic waves drops to zero because of the interference between the wavelets scattered by the periodic structures, which is essentially a diffraction effect of the periodic structures. To further broaden the transparency bandwidth and improve transmission efficiency of structured metals, we now try to exploit aperiodic structures to break the transitional symmetry and decrease the degree of ordering in the system, then weaken or even eliminate Wood’s anomalies, thus achieving broadband high transparency based on non-resonant excitations in aperiodic metallic gratings.

As shown in Figs. 1 and 2, we have demonstrated that broadband high transmission appears in aperiodic metallic gratings (including quasi-periodic and disordered ones), where quasi-periodic and disordered metallic gratings significantly weaken and even eliminate Wood’s anomalies. As results, the transparency bandwidth increases and transmission efficiency improves in the terahertz (THz) region. Based on detailed analytical solutions of Maxwell’s equations, the optimal incident angle for broadband transparency of metallic gratings
follows $\theta = \arccos(W/D)$, where $W$ represents the sum of the width of all slits, and $D$ is the total width of the sample, respectively.

![Figure 1 (left) (a) Photograph of periodic metallic grating (S1) constructed by unit $A$. (b) Photograph of periodic metallic grating (S2) constructed by unit $B$. (c) Photograph of a metallic grating with the tenth-generation Fibonacci sequence (S3) constructed by units $A$ and $B$. (d) Photograph of a metallic grating with disordered sequence (S4) constructed by units $A$ and $B$. The scale bar is 1 mm for all the four photographs. And Figure 2 (right) Experimentally measured transmission spectra of the metallic gratings S1, S2, S3, and S4, respectively. Experimentally measured transmission spectra are carried out at incident angle $\theta = 0^\circ$ and $\theta = 68^\circ$ for TM polarization. Unit sizes of units $A$ and $B$ are $p_A = 300 \mu m$ and $p_B = 500 \mu m$, strip widths of units $A$ and $B$ are $b_A = 210 \mu m$ and $b_B = 350 \mu m$, the thickness of all gratings are $h = 200 \mu m$.](image)

In summary, we have theoretically and experimentally demonstrated broadband high transmission of THz waves in quasi-periodic and disordered metallic gratings, which originates from the non-resonant excitations in the grating system. Experimental measurements at terahertz regime reasonably agree with both analytical analysis and numerical simulations. We expect that these results would be of potential applications in many fields such as transparent conducting panels and stealth objects. And the shown phenomena may also shed new light on the development of broadband metamaterials, including sonic artificial materials.

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